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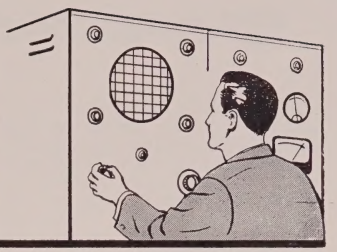

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The Aerovox Research Worker is edited and published by the Aerovox Corporation to bring to the Radio Experimenter and Engineer, authoritative, first hand information on capacitors and resistors for electrical and electronic application.

VOL. 29, NOS. 7 - 8 JULY - AUGUST, 1959 Subscription By Application Only

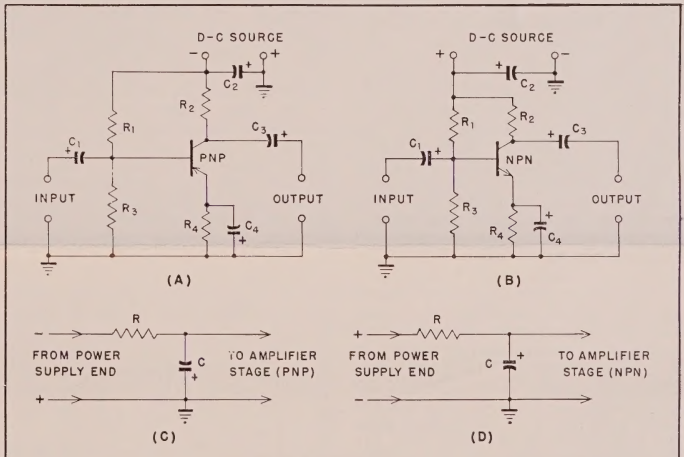
Fixed Capacitors in Transistor Circuits

By the Engineering Department, Aerovox Corporation

Transistorized equipment creates a large new application area for low-voltage capacitors. Since much of this equipment is miniaturized, it demands small-sized capacitors. The low impedances of the transistor necessitate much higher coupling and bypass capacitances, in many instances, than are employed in comparable tube circuits. In order to obtain these high capacitances in small packages, electrolytic capacitors therefore are employed in transistor circuits in positions where they seldom are found in tube circuits. This is particularly true of audio-frequency circuits. In transistorized r-f amplifiers and oscillators, and in flip-flops, multivibrators, and other switching circuits, many of the capacitances are very nearly the same as those found in similar tube circuits.

Typical Applications

Figure 1 shows single-stage, RC-coupled, common-emitter a-f amplifiers circuits. This type of circuit is widely used in sound systems, instruments, and control devices. Figure



SINGLE-STAGE COMMON-EMITTER A-F AMPLIFIERS

FIG. 1

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1(A) employs a PNP transistor, and Figure 1(B) an NPN transistor. Figures 1(C) and 1(D) show a simple decoupling filter which would be required in a multistage amplifier consisting of several cascaded RC-coupled stages. Figure 1(C) is used with the PNP circuit, and 1(D) with the NPN circuit.

All capacitors are electrolytic. Note that the polarity of **all** capacitors must be reversed when the transistor is changed from PNP to NPN. In Figures 1(A) and 1(B), C_1 and C_3 are coupling capacitors, whereas C_2 and C_4 are bypasses. D-C base bias stabilization is supplied by the voltage divider R_1-R_2, and current limiting by the emitter series resistor, R_4. The voltage division results in the application of a d-c voltage somewhat lower than the supply voltage to the base of the transistor and to the inner terminal of C_1. This voltage is negative in the PNP circuit and positive in the NPN. Unless degeneration is desired, R_4 must be bypassed heavily by means of C_4. In a preamplifier employing a conventional a-f transistor and a 6-12-volt supply, typical circuit constants are: C_1 and C_3 1 to 10 μfd (depending upon desired low-frequency response), C_2 100-200 μfd, C_4 50 μfd, R_1 100K, R_2 4.7K, R_3 10K, and R_4 1K. In the decoupling filters (Figures 1C and 1D), typical values are C 50 μfd and R 220-330 ohms in a 3-stage voltage amplifier.

Capacitor C_1 looks into a relatively low resistance comprised by the internal base-emitter resistance of the transistor in parallel with bias resistor R_3. This total resistance may be of the order of 1000 ohms. Hence, a high capacitance (1 to 10 μfd) is required in C_1 to obtain the same low-frequency response and negligible phase shift afforded by a 0.1 μfd looking into a ½ megohm grid resistor in a comparable tube circuit. When RC-coupled stages are cascaded, each output capacitor (C_3) looks into the low base-emitter input resistance of the following stage. In a tube amplifier in which the coupling capacitance C = 0.1 μfd and the grid resistance R = ½ megohm, the time constant t = 50 milliseconds. To obtain this same value with the 1000-ohm input resistance of the transistor, C = t/R = 50 μfd.

Even when the resistance of the a-f signal source is low (as in the case of a reluctance pickup or dynamic microphone), Capacitor C_1 is required to withstand only the steady d-c voltage developed at the junction of R_1 and R_3. Since this potential is much lower than the supply voltage, a capacitor rated at a continuous d-c working voltage equal to the supply voltage will provide more than adequate safety factor. Actually, a much lower dcwv rating may be tolerated here when miniaturization demands a smaller-sized (lower-voltage) capacitor, since in the circuits shown in Figures 1(A) and 1(B), the transistor base voltage is about one-tenth of the supply voltage.

The output coupling capacitor, C_3, being connected directly to the collector of the transistor, must be rated to withstand continuously the d-c supply voltage (less the drop across R_2) plus the peak value of the collector signal voltage. The d-c voltage drop **e** developed across the emitter resistor, R_4, is equal to $i_e R_4$, where i_e is the d-c emitter current. Bypass capacitor C_4 accordingly must be rated to withstand continuous voltage **e** plus the peak value of the a-f signal voltage developed across R_4. The dcwv requirement of C_4 generally will be less than one-half that of C_3. For simplicity, however, capacitors of the same voltage rating often are used in both positions.

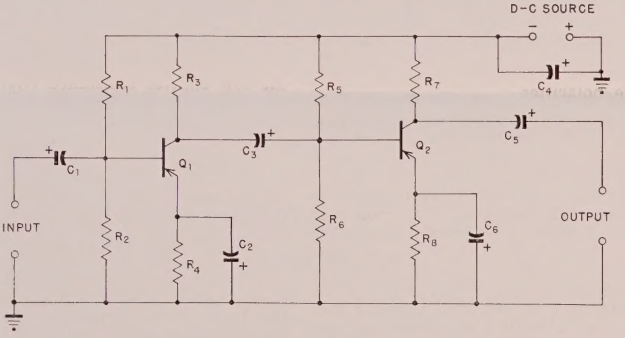
In a multistage circuit, the situation is slightly different. The interstage coupling capacitor (C_3 in Figure 2) has the negative collector voltage of Transistor Q_1 applied to its negative terminal, and the lower negative bias voltage at the base of Transistor Q_2 applied to its positive terminal. (If NPN transistors are used, all voltage and capacitor polarities are reversed.) Capacitor C_3 accordingly must be rated to withstand continuously the d-c supply voltage (less the drop across R_3) plus the peak value of the Q_1 collector signal voltage. Capacitor C_5 must be similarly rated with respect to the d-c and a-f collector voltages of Transistor Q_2. The dcwv ratings of bypass capacitors C_2 and C_6, like C_4 in the single-stage amplifier, are less than one-half those of C_3 and C_5; but for simplicity, capacitors of the same rating often are used.

To prevent damage to coupling capacitors in circuits handling high signal-voltage levels, capacitors having sufficiently high dcwv ratings to insure a good safety factor must be employed. Since the total voltage applied to the capacitor is the sum of d-c and signal voltages, the d-c rating of the capacitor can be exceeded during the high signal-voltage peaks if the capacitor is selected only on the basis of the d-c voltage expected in the circuit.

For good safety factor, the supply bypass capacitor (C_2 in Figure 1 and C_4 in Figure 2) should have a dcwv rating equal to twice the supply voltage. The filter capacitor in the decoupling network (C in Figures 1C and 1D) should be similarly rated.

Importance of Low Leakage

The necessity that leakage currents be low in miniature electrolytic coupling capacitors in transistor circuits is apparent from an inspection of Figure 2. The voltage divider networks (R_1-R_2 and R_5-R_6) stabilize the d-c base bias of the transistors. This



C_1, C_3, C_5 - 1-10 μFD.
C_2, C_6 - 50 μFD.
C_4 - 100-200 μFD.

R_1, R_5 - 100K
R_2, R_6 - 10K
R_3, R_7 - 5K
R_4, R_8 - 1K

2-STAGE COMMON-EMITTER A-F AMPLIFIER

FIG. 2

stabilization provides some temperature compensation, as well as minimizing changes in operation when transistors are interchanged or replaced. Very importantly, the d-c bias also sets the operating point of the transistor along its characteristic curve, so that Class-A operation, for example, is secured. If the leakage of Capacitor C_3 is high, the voltage at the junction of R_5 and R_6 will be raised to some value approaching the collector potential of Transistor Q_1. This change in voltage will shift the operating point of Transistor Q_2, resulting in distortion, and will alter the stabilization provided by the voltage divider. Additionally, the lowered impedance of C_3 will alter the gain and phase shift characteristics of the amplifier. High leakage in C_3 will also reduce the d-c collector voltage of Q_1.

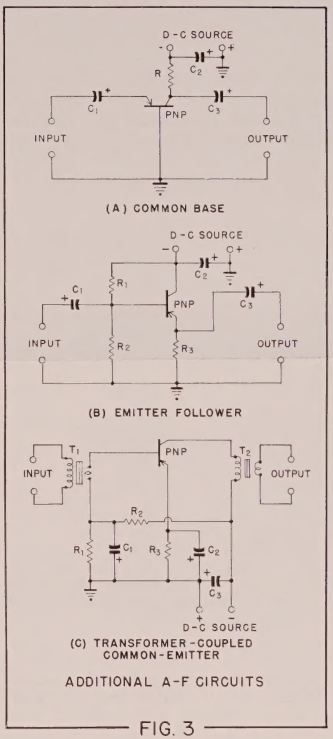
High leakage in C_5 will cause a d-c component to be applied to the load device (or following amplifier stage) connected to the OUTPUT terminals. In short, d-c leakage must be low enough that a coupling capacitor does not transmit a significant d-c component and that a bypass capacitor does not materially reduce the d-c resistance of the path in which it is included.

Additional A-F Circuits

The RC-coupled common-emitter circuit presently is the most widely used in transistorized a-c signal circuits. Its general appeal is due to its high power gain, fair-to-good frequency response, and moderate input impedance. Figure 3 shows additional circuit arrangements in which the correct polarity of electrolytic capacitors is indicated. PNP transistors are shown. If NPN transistors are used, reverse **all** capacitor and voltage polarities.

Figure 3(A) shows a common-base stage. The input resistance of the transistor is very low (50 ohms with some transistors). The input coupling capacitor, C_1, therefore must be quite high in order to obtain the same frequency response, phase shift, and gain supplied by comparable common-emitter and tube circuits. Whereas an input coupling capacitance of 1 to 10 μfd (Figures 1 and 2) is suitable for the common-emitter circuit, C_1 will be 10 to 50 μfd in the common-base circuit, depending upon type of transistor and desired low-frequency response. The capacitance of C_3 will not be so high (generally 1 to 10 μfd) unless the load device has low resistance.

Figure 3(B) shows an emitter follower stage. This configuration provides high input impedance, low output impedance, wide frequency range, and no phase shift; and in these respects is similar to the cathode follower tube. Here, Capacitors C_1 and C_2 have the same values specified earlier for the common-emitter circuit. Output coupling capacitor C_3 is effectively in series with the low emitter resistance (R_3) and the low resistance external load device. This capacitance accordingly must be high and usually is of the order of 50 to 1000 μfd, depending upon the values of R_3 and R_L (external load), and the desired low-frequency response.



ADDITIONAL A-F CIRCUITS

FIG. 3

Figure 3(C) shows a transformer-coupled common-emitter stage in which the d-c bias, developed by the R_1-R_2 voltage divider, is applied to the base of the transistor through the secondary winding of input transformer T_1. This arrangement often is used in power transistor stages, the bias network being placed in this position instead of across the input terminals (as in Figures 1 and 2) because the lower resistor would absorb some of the input signal. Here, it is necessary to bypass heavily to prevent loss of signal voltage across the lower network resistor, R_1. The bypass capacitance, C_1 must be high, since R_1 usually is low (commonly 100 to 1000 ohms). C_1 will have a value between 50 and 500 μfd, depending upon the transistor type and R_1 resistance. Bypass Capacitance C_2 likewise must be high, since R_3 (especially in power transistor stages) may be only a few ohms. This capacitance will be 100 to 1000 μfd, depending upon transistor type and R_3 resistance.

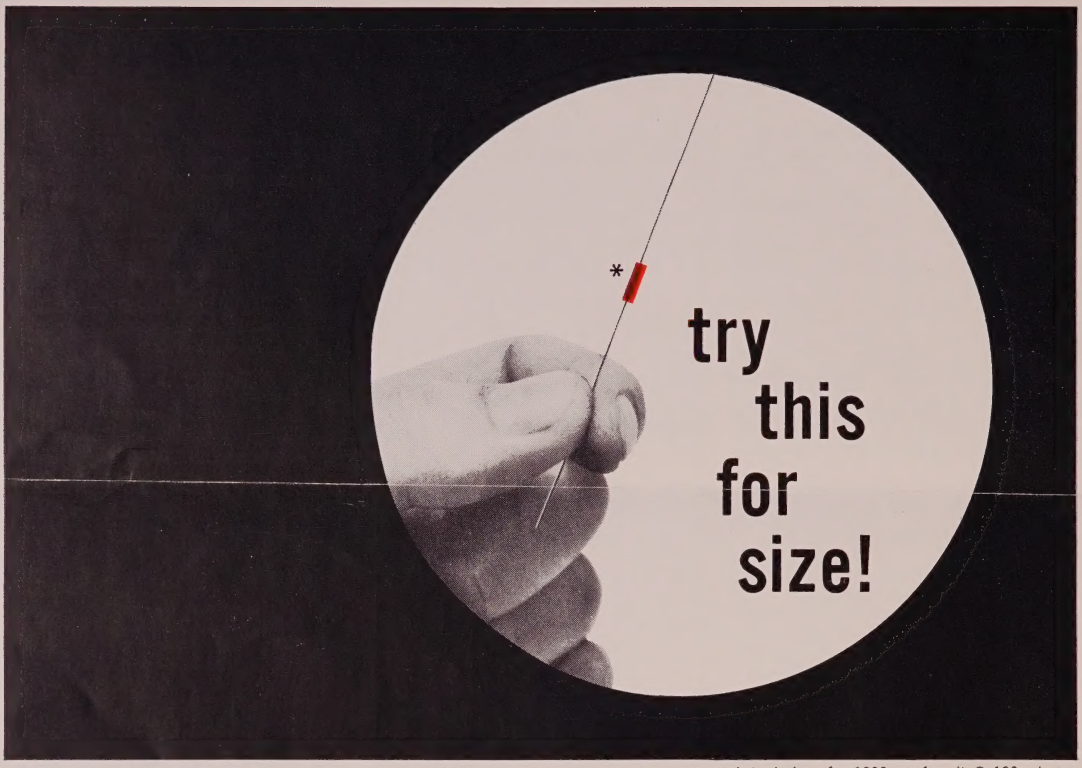
Capacitors in R-F and Switching Circuits

The majority of capacitances employed in r-f amplifier, oscillator, and oscillator circuits, including intermediate-frequency devices, extend from 5 μμfd to 0.1 μfd. This is true also of switching circuits, including flip-flops, multivibrators, Schmitt triggers, pulse amplifiers and inverters, single-shots, etc. These capacitances are obtainable in miniature nonelectrolytic capacitors, such as mica, ceramic, and (in the higher capacitances) metallized paper types. Therefore, there is no polarity problem. These capacitors normally are rated to withstand much higher d-c voltages than ordinarily are encountered in transistor circuits consequently, voltage rating is no problem either.

An occasional high capacitance, such as 10 μfd, is required for avc filtration or for d-c supply bypassing, and a miniature electrolytic is employed in such instances. Here, the rules discussed earlier apply to this capacitor. That is, the dcwv rating of the capacitor must exceed the sum of the supply voltage and signal-voltage peak, and the polarity is determined by whether the transistor is NPN or PNP.

A wide selection of miniature mica and ceramic capacitors is available for use in r-f and switching circuits. The choice of a particular type will depend upon space requirements and, to some extent, upon whether conventional or printed-circuit construction is employed.

Because of their very high insulation resistance, nonelectrolytic capacitors in transistor circuits present no leakage problems unless the capacitors are damaged. The designer of new equipment in which capacitors are employed in frequency-determining circuits must pay particular attention to the magnitude and direction of the temperature-capacitance coefficient of ceramic capacitors to prevent undesired frequency shift from this source. And the technician who replaces these capacitors in maintaining transistorized equipment must take special pains to use **exact** replacements.



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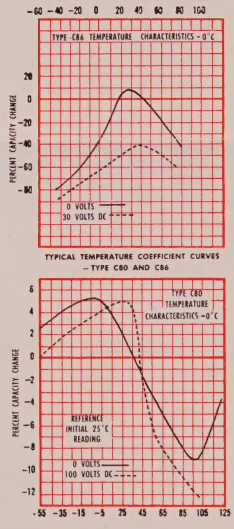

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